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Floor Dust Bacteria and Fungi and their Coexistence with PAHs in Jordanian Indoor Environments

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Abstract

Floor dust samples were collected from Jordanian indoor environments (eight dwellings and an educational building) in Amman. Quantitative PCR (qPCR) analyses of selected fungal and bacterial groups were performed. The bacterial and fungal concentrations were also correlated with PAHs concentrations, which were previously measured in the same samples by using GC-MS. The bacterial and fungal concentrations varied significantly among and within the tested indoor environments. Based on the collected samples in the entrance area of the dwellings, the largest variation was found in Gram-negative bacteria and total fungi concentration. The lowest bacterial and fungal concentrations were found in the dwelling that was least occupied and the most recently built. At the educational building, the Gram-positive bacteria concentrations were lower than those observed in the dwellings. The biocontaminants showed a clear correlation with some polycyclic aromatic hydrocarbons (PAHs). This suggests that the tested indoor environments might be at high risk of exposure to PAHs metabolite. Since biocontamination in floor dust has been given relatively little to no attention in the MENA region we recommend that more extensive measurements be conducted in the future with chemical and biological analysis of floor dust contaminants and their exposure indoors.

Keywords: Gram-positive, Gram-negative, *Penicillium/Aspergillus* spp., Total fungi, Dwellings, Educational building.

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1. Introduction

Pollution has been a general and common problem for a long time (e.g. Morawska et al., 2013). Exposure to pollution can occur via three main routes: dermal, inhalation, and ingestion causing health problems (e.g. Alam et al., 2014; Grimsley et al., 2012; Günther et al., 1998).

Particularly, household dust accommodates a vast range of biological contamination, which includes microbes (i.e. microorganisms such as fungi, bacteria, and viruses) and non-microbes (such as insects and their dry parts, dust-mites, and cells from humans, plants, and animals). In general, biological contamination have limited direct toxicity on humans but they are often involved in the etiology of building related illness that is either infective or allergic as well as resulting in decreased lung function, respiratory symptoms, asthma and rhinitis, and sick-building syndrome (e.g. Morawska et al., 2013; Mandal and Brandl, 2011; Ross et al., 2000).

The dynamic behavior of biological contamination in the indoor air and floor dust can be described mathematically by means of a material-balance equation (e.g. Bhangar et al., 2014; Nazaroff, 2014; Meadow et al., 2013; Nazaroff and Cass, 1989), which includes several terms to describe the controlling factors (sources and sinks) of the concentration change rate in both the air and the floor dust. The outdoor air concentration of any contaminant drives its concentration indoors via the indoor-outdoor air exchange (i.e. ventilation rate) and the penetration factor (filtration and infiltration), which are the main building characteristics defining the indoor-to-outdoor relationship of air pollutants (e.g. Hussein et al., 2015; Hussein and Kulmala, 2008; Nazaroff, 2004). The production, survival, and decay of bacteria and fungi inside floor dust is affected by many factors: (1) their airborne concentrations, (2) building characteristics (e.g. ventilation, penetration, type of interior surfaces, etc.), (3) occupants and their activities, (4) environmental conditions, and (5) coexistence with chemical pollution (such as polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs)).

It was reported that the fate of PAHs in soil is affected by various factors including biological diversity and abundance (Gupte et al., 2016; Semple et al., 2003; Reid et al., 2000; Heitkamp et al., 1988). Wood-decaying fungi can detoxify, oxidize, and transform PAH (e.g. Günther et al., 1998). A long time ago, it was also confirmed that some microbial metabolites of naphthalene occur in microcosms containing natural freshwater and estuarine sediments (Heitkamp et al., 1987). As an advantage, PAHs can be removed by using microbial and fungal degradation, which is a natural technique (e.g. Leitão, 2009; Johnsen et al., 2006; Munoz et al., 2003).

In this study, the aim was to quantify fungal and bacterial concentrations inside floor dust samples collected from dwellings and an educational building in Amman, Jordan. We also applied simple statistical tests between the tested microbe concentrations and the PAHs concentrations.

2. Materials and Methods

2.1 Floor dust samples

Floor dust samples were collected during April 3–9, 2015 from eight dwellings and an education building located in Amman, Jordan (Figure 1). These indoor environments were naturally ventilated. The weather condition (T, RH, and precipitation) during this period is presented in Figure S1. The collection procedure of floor dust samples and detailed description about the dwellings and the education building can be found in our previous studies Maragkidou et al. (2016 and 2017). Here, we provide this information in brief.

Two samples were taken from each dwelling (living room and main entrance). In order to collect a reasonable amount of floor dust samples, the dwellings were not vacuum cleaned for 3-4 days before samples were collected. The type and age of each dwelling as well as the type and area of the floor are given in Table S1. The educational building was the Department of Physics of the University of Jordan (Table S2 and Figure S2). All samples were collected on the same day. The cleaning staff executed their routine daily cleaning activities normally. Although smoking was prohibited inside the university buildings, sometimes this was violated.

As described by Maragkidou et al. (2016 and 2017). The floor dust samples were collected by using a regular vacuum cleaner. We placed the vacuum dust bags made of nylon (25 μ m, 155 mm \times 73/38 mm, Allied Filter Fabrics Pty. Ltd) inside the tube of the vacuum cleaner. Each sample was collected from 3 minutes of vacuum cleaning and a floor surface area as listed in Tables S1 and S2. Immediately after dust collection, the dust bags were closed and put inside a zipped plastic bag. Each dust sample was then put in a glass vial, wrapped with aluminum foil and stored in the freezer (-20 °C). Shipment to the laboratory was undertaken at room temperature and samples were stored in the laboratory at -20 °C until analyses were completed.

2.2 Biological analysis

DNA was extracted from weighted samples of dusts of approximately 20 mg using Chemagic DNA Plant kit (PerkinElmer chemagen Technologie GmbH, Germany) on KingFisher mL magnetic bead based DNA extraction robot (Thermo Scientific, Finland). In an initial step, microbial cells were disrupted with bead-beating as described in (Kärkkäinen et al. 2010), using MiniBeadBeater-16

(Biospec Products Inc). Salmon tests DNA (Sigma Aldrich, USA) was added as an internal standard to the samples prior to DNA extraction (Haugland et al. 2012) to account for PCR inhibitors and variability in DNA extraction efficiency.

Quantitative PCR (qPCR) analyses of selected fungal and bacterial groups and calculations of cell equivalents per mg of dust were performed as described by Kaarakainen et al. (2009). qPCR assays used in this study have been published previously as follows: total fungal DNA (Haugland & Vesper, US pat. 2002; 6 387 652), group of *Aspergillus* spp./*Penicillium* spp./*Paecilomyces variotii* (Haugland et al. 2004), and Gram-positive and Gram-negative bacteria (Kärkkäinen et al. 2010). QPCR reactions were performed as written in the original publications with minor modifications. In the bacterial duplex assay 20 µl reaction mix included 10 µl of Environmental Master Mix (Applied Biosystems Inc., Foster City, CA), 1.5 µl Bovine serum albumin (2mg/ml), 1 µl of forward and reverse primers, 0.4 µl of a both TaqMan probes, 3.7 µl of nuclease free water (HyClone Laboratories Inc., Utah, USA) and 2 µl of template DNA. The analysis was performed on Stratagene Mx3005P QPCR System (Agilent Technologies Inc., USA) equipment.

2.3 Polycyclic aromatic hydrocarbons (PAHs)

The polycyclic aromatic hydrocarbons (PAHs) concentrations were previously investigated by Maragkidou et al. (2016) for the dwellings and by Maragkidou et al. (2017) for the educational building (Tables S3 and S4). The PAHs concentrations were quantified via GC-EI/MS.

3. Results and discussion

3.1 Bacterial and fungal contamination

The bacterial and fungal concentrations in the dwellings varied significantly in both the entrance and living room (Table S5 and Figure 2). The Gram-positive bacteria concentrations in the entrance were 17700–95800 CE/mg (excluding the extreme value at A3, ~348300 CE/mg) and the Gram-negative bacteria were 8900–2254300 CE/mg. As for *Penicillium/Aspergillus* spp., it was in the range 200–7300 CE/mg and total fungi concentrations were 500–35100 CE/mg (excluding the extreme value at A2, ~172300 CE/mg). As for the living room, the Gram-positive bacteria concentrations were 11300–265400 CE/mg (excluding the extreme value at A3, ~959100 CE/mg) and the Gram-negative bacteria were 20700–423000 CE/mg. As for *Penicillium/Aspergillus* spp., it was in the range 600–26400 CE/mg and total fungi concentrations were 600–7700 CE/mg (excluding the extreme value at DH3, ~30200 CE/mg). Dwelling A4, which was the least occupied and the most recently built, had the lowest concentrations of fungi and Gram-negative bacteria in both the entrance and living room.

It also had the lowest Gram-positive bacteria concentrations in the living room whereas dwelling DH4 had the lowest Gram-positive bacteria concentrations in the entrance.

At the educational building, the Gram-positive bacteria concentrations (5300–136000 CE/mg) and *Penicillium/Aspergillus* spp. concentrations (200–5100 CE/mg) were lower than those observed in the dwellings (Tables S5 and S6 and Figures 2 and 3). As for the Gram-negative bacteria, the concentrations at the education building (38700–495000 CE/mg) were higher than those observed at the dwellings. The total fungi concentrations at the educational building (800–10700 CE/mg) were in the same range as those in the dwellings. Both corridors (BC and C1) had the highest concentrations of Gram-positive bacteria whereas the workshop had the lowest concentrations. All offices, lecture rooms, and the corridors had Gram-negative concentrations higher than 1×10^5 CE/mg whereas the workshop had concentrations less than 1×10^5 CE/mg. The main corridor/first floor (C1) had the lowest *Penicillium/Aspergillus* spp. concentration whereas the workshop welding area had the highest concentration. The big corridor (BC) located at the main entrance/ground floor had the highest total fungi concentration whereas the welding area at the workshop had the lowest concentration.

Tischer et al. (2015) reported *Penicillium/Aspergillus* spp. as well as Gram-positive and Gram-negative bacteria concentrations inside houses in Europe. When compared to this study, *Penicillium/Aspergillus* spp. and Gram-positive bacteria were lower compared to most European countries, but Gram-negative bacteria concentrations appeared to be rather high. This could indicate that human source derived mostly Gram-positive bacteria are somewhat less in Jordan dwelling dust, and Gram-negative bacteria from mostly environmental sources - hypothetically - are more dominant. This is hypothetical though as we were limited by the number of samples taken and without identification of the bacteria with e.g. NGS.

The differences in bacterial and fungal concentrations amongst the studied indoor environments in this study indicate that sources of biocontamination are different in different locations of the city. Adams et al. (2014) confirmed that indoor fungi and bacteria that are originated from outdoor sources vary in space and time, which relates to environmental conditions as being major factors affecting the concentrations of biological content of indoor floor dust. Weigl et al. (2016) made it evident that indoor fungi are more affected than bacteria by certain environmental conditions such as vegetation, urbanization, and outdoor particulate matter. For example, fungal communities in indoor dust changed semi-annually whereas bacterial communities followed outdoor plant phenological periods. The small variations in gram- positive bacteria indoors could be attributed to the positive strains tolerance to dry conditions which manage them to grow without the presence of mold in contrary to negative- bacteria (Adhikari et al., 2014).

Also, it is well known that humans' activities are major sources of bacteria; in particular, Gram-positive bacteria, in house dust (e.g. Meadow et al., 2013; Täubel et al., 2009; Goh et al., 2000). This was primarily attributed to increased human shedding of skin cells, ejection of microorganisms and particulates from the respiratory tract, and the transport of bacteria on suspended dust particles from floor surfaces. Several other studies have also confirmed that occupancy and occupants' activities increased bacterial concentrations indoors (e.g. Weigl et al., 2016; Bhangar et al., 2014; Meadow et al., 2013). Unfortunately, the source origin (as indoors or outdoors) of bacteria and fungi inside the dwellings was not able to be identified in our study due to a lack of information about occupancy and activities, building characteristics, and environmental conditions. Further investigation on this is needed in the future.

In addition to occupancy and outdoor sources, environmental conditions (e.g. temperature, relative humidity, moldiness, etc.) might also be a driving factor for increasing concentrations of bacteria and fungi indoors. Goh et al. (2000) showed that the concentration of fungal spores inside a library was fifty times lower than outdoors due to a lower relative humidity indoors. Grimsley et al. (2012) showed that rain and flooding caused by Hurricane Katrina in the U.S resulted in widespread growth of mold and bacteria indoors.

Among building characteristic, floor type is a very important factor for the survival of biological contamination. Foarde and Berry (2004) illustrated that carpet flooring was not a major contributor to airborne concentrations of biocontaminants in two schools. They also showed that carpeted surfaces have higher surface loadings of the biocontaminants. On the other hand, airborne concentrations were significantly higher over tiled floors, possibly linking to better resuspension of floor dust on tiled flooring.

Biological contamination in floor dust has not been given enough attention in the Middle East and North Africa (MENA). Ali et al. (2014) investigated the bacteriological quality of water and carpets inside mosques in Elkhomes city in Libya; they suggested that mosques, as communal environments, may play a role in the spread of multidrug-resistant bacteria in the community and pose a serious health risk to worshipers in case the carpets are not treated against microbe contamination. We also found three studies conducted in Egypt and another in Iran, but they all considered bioaerosols.

3.2 Correlations between bacteria, fungi and PAHs concentrations

We examined Spearman's rank correlation coefficient between the biological contamination (bacterial and fungal concentrations) and PAHs concentrations. The statistical sample size for each type of dwelling was too small to enable reliable estimates separately for different areas of the building or type of dwelling; therefore, we applied the analysis for all samples combined (Table S7).

Gram-positive bacteria had a reasonably moderate positive correlation with phenanthrene only whereas Gram-negative bacteria had significant positive correlation with fluoranthene and pyrene only. Biodegradation of PAHs containing more than three aromatic rings is not very well understood because of their large size and extreme insolubility; fluoranthene and pyrene are examples of such PAHs (Mrozik et al., 2003). Interestingly, mycobacteria have been repeatedly isolated as bacteria that can degrade pyrene and benzo[a]pyrene. Although these bacteria are known for their comparatively slow growth, their growth on PAHs is faster than other bacteria (Mrozik et al., 2003).

Penicillium/Aspergillus spp had a moderate to strong negative correlations with anthracene, fluoranthene, benzo(b)fluoranthene, and benzo(j)fluoranthene. Total fungi showed significant negative correlations with anthracene, benz(a)anthracene, and dibenz(a-h)anthracene. Maigari et al. (2015) explained that *Penicillium/Aspergillus* spp, which are non-ligninolytic fungi, uses cytochrome P₄₅₀-mediated oxidation mechanism. This was tested to have the tendency and ability to degrade or metabolite anthracene, fluoranthene, benzo(b)fluoranthene, and benzo(j)fluoranthene. Total fungi includes all types (non-ligninolytic and ligninolytic). Ligninolytic fungi utilize different metabolic pathways but they can degrade a wide range of PAHs (Maigari et al., 2015).

In general, many studies have shown that bacteria and fungi metabolite PAHs (e.g. Gupte et al., 2016; Munoz et al., 2003; Semple et al., 2003; Reid et al., 2000; Heitkamp et al., 1987 and 1988). They transform PAHs to activated products such as diol-oxides (PAHs metabolites by the cytochrome P-450 or similar mechanisms). This is expected to have increased health risk from the exposure to PAHs activated products diol-oxides that mutate humans' DNA and RNA (e.g. Igwe and Ukaogo, 2015; Skupinska et al., 2004; IARC 1983).

4. Conclusion

The bacterial and fungal concentrations varied significantly among and within the studied indoor environments. This variation indicates that indoor and outdoor sources are different in different locations of the city. The lowest bacterial and fungal concentrations were found in the dwelling that was least occupied and the most recently built.

The bacterial and fungal concentrations showed clear correlations with some PAHs concentrations. The Gram-positive bacteria had a reasonably moderate positive correlation with phenanthrene whereas Gram-negative bacteria had significant positive correlations with fluoranthene and pyrene. *Penicillium/Aspergillus* spp. had moderate to strong negative correlations with anthracene, fluoranthene, benzo(b)fluoranthene, and benzo(j)fluoranthene. Total fungi concentration showed significant negative correlations with anthracene, benz(a)anthracene, and dibenz(a-h)anthracene.

This means that occupants in such indoor environments are at high risk of exposure to PAHs metabolite, which are active and carcinogenic products.

It is expected that exposure to PAHs metabolites (e.g. by the cytochrome P-450 or similar mechanisms) might have increased health risk for humans and indoor pets. For instance, it might mutate humans' DNA and RNA.

Since biocontamination in floor dust has been given relatively little attention in the MENA region we recommend that more extensive measurements be conducted in the future with chemical and biological analysis of floor dust contaminants and their exposure indoors.

Acknowledgements

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References

- Adhikari, A., Kettleson, E.M., Vesper, S., Kumar, S., Popham, D.L., Schaffer, C., Indugula, R., Chatterjee, K., Allam, K.K., Grinshpun, S.A., Reponen, T., 2014. Dustborne and airborne Gram-positive and Gram-negative bacteria in high versus low ERMI homes. *Sci. Total Environ.* 482–483, 92–99.
- Alam, M.J., Anu, A., Walk, S.T., Garey, K.W., 2014. Investigation of potentially pathogenic *Clostridium difficile* contamination in household environs. *Anaerobe* 27, 31–33.
- Ali, M.M.M., Alemamy, F., Alrtail, A., Rzeg, M.M., Albakush, A.M., Ghenghesh, K.S., 2014. High isolation rates of multidrug-resistant bacteria from water and carpets of mosques. *Libyan J. Med.* 9, 25415–2518.
- Bhangar, S., Huffman, J.A., Nazaroff, W.W., 2014. Size-resolved fluorescent biological aerosol particle concentrations and occupant emissions in a university classroom. *Indoor Air* 24, 604–617.
- Cerniglia, C. E. 1984. Microbial metabolism of polycyclic aromatic hydrocarbons. *Adv. Appl. Microbiol.* 30, 31–71.
- Foarde, K., Berry, M., 2004. Comparison of biocontaminant levels associated with hard vs. carpet floors in nonproblem schools: results of a year long study. *J. Expo. Anal Environ. Epidemiol.* 14, Suppl 1, 41–48.
- Goh, I., Obbard, J.P., Viswanathan, S., Huangy, Y., 2000. Airborne bacteria and fungal spores in the indoor environment. A case study in Singapore. *Acta Biotechnol.* 20, 67–73.
- Grimsley, L. F., Chulada, P. C., Kennedy, S., White, L., Wildfire, J., Cohn, R.D., Mitchell, H., Thornton, E., El-Dahr, J., Mvula, M.M., Sterling, Y., Martin, W.J., Stephens, K.U., Lichtveld M., 2012. Indoor environmental exposures for children with asthma enrolled in the HEAL Study, Post-Katrina New Orleans. *Environ. Health Perspect.* 120, 1600–1606.

- Gupte, A., Tripathi, A., Patel, H., Rudakiya, D., Gupte, S., 2016. Bioremediation of Polycyclic Aromatic Hydrocarbon (PAHs): A Perspective. *The Open Biotechnology Journal* 10 (Suppl-2, M9), 363–378.
- Günther, T., Sack, U., Hofrichter, M., Lätz, M., 1998. Oxidation of PAH and PAH-derivatives by fungal and plant oxidoreductases. *J. Basic Microbiol.* 38, 113–122.
- Haugland, R.A., Siefring, S., Lavender, J., Varma, M., 2012. Influences of sample interference and interference controls on quantification of enterococci fecal indicator bacteria in surface water samples by the qPCR method. *Water Research* 46, 5989–6001.
- Haugland, R.A., Varma, M., Wymer, L.J., Vesper, S.J., 2004. Quantitative PCR analysis of selected *Aspergillus*, *Penicillium* and *Paecilomyces* species. *Syst. Appl. Microbiol.* 27, 198–210.
- Heitkamp, M. A., Franklin, W., Cerniglia, C. E., 1988. Microbial Metabolism of Polycyclic Aromatic Hydrocarbons: Isolation and Characterization of a Pyrene-Degrading Bacterium. *App. Environ. Microbiol.* 54, 2549–2555.
- Heitkamp, M. A., Freeman, J. P., Cerniglia, C. E., 1987. Naphthalene biodegradation in environmental microcosms: estimates of degradation rates and characterization of metabolites. *Appl. Environ. Microbiol.* 53, 129–136.
- Hussein, T., Kulmala, M., 2008. Indoor aerosol modeling: basic principles and practical applications. *Water Air Soil poll. Focus* 8, 23–34.
- Hussein, T., Wierzbicka, A., Löndahl, J., Lazaridis, M., Hänninen, O., 2015. Indoor Aerosol Modeling for Assessment of Exposure and Respiratory Tract Deposited Dose. *Atmos. Environ.* 106, 402–411.
- Igwe, J. C., Ukaogo, P. O., 2015. Environmental Effects of Polycyclic Aromatic Hydrocarbons. *J. Natural Sci. Res.* 5, 117 – 131.
- International Agency for Research on Cancer (IARC), 1983. Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental and Experimental Data, IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Vol. 32, Lyon, France, pp. 33–91.
- Jacobs, J., Borràs-Santos, A., Krop, E., Täubel, M., Leppänen, H., Haverinen-Shaughnessy, U., Pekkanen, J., Hyvärinen, A., Doekes, G., Zock, J.-P., Heederik, D. 2014. Dampness, bacterial and fungal components in dust in primary schools and respiratory health in schoolchildren across Europe. *Occup. Environ. Med.* 71, 704–712.
- Johnsen, A. R., de Liphay, J. R., Sørensen, S. J., Ekelund, F., Christensen, P., Andersen, O., Karlson, U., Jacobsen, C. S. 2006. Microbial degradation of street dust polycyclic aromatic hydrocarbons in microcosms simulating diffuse pollution of urban soil. *Environ. Microbiol.* 8, 535–545.
- Karakainen, P., Rintala, H., Vepsäläinen, A., Hyvärinen, A., Nevalainen, A., Meklin, T., 2009. Microbial content of house dust samples determined with qPCR. *Sci. Total Environ.* 407, 4673–4680.
- Kärkkäinen, P.M., Valkonen, M., Hyvärinen, A., Nevalainen, A., Rintala, H., 2010. Determination of bacterial load in house dust using qPCR, chemical markers and culture. *J. Environ. Monit.* 12, 759–68.
- Leitão, A. L., 2009. Review: Potential of *Penicillium* Species in the Bioremediation Field. *Int. J. Environ. Res. Public Health* 6, 1393–1417.
- Mandal, J., Brandl, H., 2011. Bioaerosols in indoor environment - A review with special reference to residential and occupational locations. *Open Environ. Biol. Monit. J.* 4, 83–96.
- Maragkidou, A., Arar, S., Al-Hunaiti, A., Ma, Y., Harrad, S., Jaghbeir, O., Faouri, D., Hämeri, K., Hussein, T., 2016. Occupational health risk assessment and exposure to floor dust PAHs inside an educational building. *Sci. Total Environ.* (in press, <http://dx.doi.org/10.1016/j.scitotenv.2016.11.055>).

- Maragkidou, A., Ma, Y., Jaghbeir, O., Faouri, D., Harrad, S., Al-Hunaiti, A., Arar, S., Hameri, K., Hussein, T., 2016. PAHs in household floor dust collected in Amman, Jordan. *J. Chem. Eng. Process Technol.* 7:292.
- Meadow, J.F., Altrichter, A.E., Kembel, S.W., Kline, J., Mhuireach, G., Moriyama, M., Northcutt, D., O'Connor, T.K., Womack, A.M., Brown, G.Z., Green, J.L., Bohannon, B.J., 2014. Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. *Indoor Air* 24, 41–48.
- Morawska, L., Afshari, A., Bae, G.N., Buonanno, G., Chao, C.Y., Hänninen, O., Hofmann, W., Isaxon, C., Jayaratne, E.R., Pasanen, P., Salthammer, T., Waring, M., Wierzbicka, A., 2013. Indoor aerosols: from personal exposure to risk assessment. *Indoor Air* 23, 462–487.
- Mrozik, A., Seget, P.T., Lubuzek, S., 2003. Bacterial degradation and bioremediation of polycyclic aromatic hydrocarbons. *Polish Journal of Environmental Studies* 12, 15–25.
- Muñoz, R., Guieysse, B., Mattiasson, B., 2003. Phenanthrene biodegradation by an algal-bacterial consortium in two-phase partitioning bioreactors. *Appl. Microbiol. Biotechnol.* 61, 261–267.
- Nazaroff, W.W., 2004. Indoor particle dynamics. *Indoor Air Suppl* 7, 175–183.
- Nazaroff, W.W., 2016. Indoor bioaerosol dynamics. *Indoor Air* 26, 61–78.
- Nazaroff, W. W., Cass, G. R. 1989. Mathematical Modeling of Indoor Aerosol Dynamics. *Environmental Science and Technology* 23, 157–166.
- Reid, B. J., Jones, K. C., Semple, K. T., 2000. Bioavailability of persistent organic pollutants in soils and sediments: a perspective on mechanisms, consequences and assessment. *Environ. Pollut.* 108, 103–12.
- Ross, M. A., Curtis, L., Scheff, P. A., Hryhorczuk, D. O., Ramakrishnan, V., Wadden, R. A., and Persky, V. W., 2000. Association of asthma symptoms and severity with indoor bioaerosols. *All.* 55, 705–711.
- Semple, K. T., Morriss, A. W., Paton, G. I., 2003. Bioavailability of hydrophobic organic contaminants in soils: fundamental concepts and techniques for analysis. *Eur. J. Soil. Sci.* 54, 809–18.
- Skupinska, K., Misiewicz, I., Kasprzycka-Guttman, T., 2004. Polycyclic aromatic hydrocarbons: physicochemical properties, environmental appearance and impact on living organisms. *Acta Poloniae Pharmaceutica – Drug Research* 61, 233–240.
- Tischer, C., Zock, J.-P., Valkonen, M., Doeke, G., Guerra, S., Heederik, D., Jarvis, D., Norbäck, D., Olivieri, M., Sunyer, J., Svanes, C., Täubel, M., Thiering, E., Verlato, G., Hyvärinen, A., Heinrich, J. 2015. Predictors of microbial agents in dust and respiratory health in the Ecrhs. *BMC Pulmonary Medicine* 48.
- Täubel, M., Rintala, H., Pitkäranta, M., Paulin, L., Laitinen, S., Pekkanen, J., Hyvärinen, A., Nevalainen, A., 2009. The occupant as a source of house dust bacteria. *J. Allergy Clin. Immunol.* 124, 834–839.
- Weigl, F., Tischer, C., Probst, A.J., Heinrich, J., Markevych, I., Jochner, S., Pritsch, K., 2016. Fungal and bacterial communities in indoor dust follow different environmental determinants. *PLoS ONE* 11, e0154131.

Figures captions

Figure 1: A map of Amman with site locations of the dwellings marked with yellow landmarks (abbreviations as listed in Table S1) and the campus of the University of Jordan (marked with red, see also Figure S2 and Table S2).

Figure 2: Bacterial and fungal concentrations in the floor dust samples collected at the dwellings: (upper) entrance area and (lower) living room area. *The abbreviations: G.+ve, G.-ve, P.Asp., and Fung refer to Gram-positive bacteria, Gram-negative bacteria, Penicillium/Aspergillus spp., and total fungi; respectively.*

Figure 3: Bacterial and fungal concentrations in the floor dust samples collected at the educational building. *The abbreviations: G.+ve, G.-ve, P.Asp., and Fung refer to Gram-positive bacteria, Gram-negative bacteria, Penicillium/Aspergillus spp., and total fungi; respectively.*

Supplementary Information

“Floor Dust Bacteria and Fungi and their Coexistence with PAHs in Jordanian Indoor Environments”

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Table S1: Features of the dwellings and floor, where the dust samples were collected.

Code	Age [years]	Type	Level in Building	Location in Dwelling	Area [m ²], Type	Date
DH2	10	Detached House	2 nd floor	Entrance	0.75 × 0.50, carpet	April 3
				Living room	1.00 × 1.00, carpet	
A2	5	Apartment	2 nd floor	Entrance	0.91 × 0.60, carpet	April 3
				Living room	1.00 × 1.00, carpet	
DH3	30	Detached House	Ground floor	Entrance (inside)	2.00 × 2.00, carpet	April 3
				Living room	2.00 × 2.00, carpet	
DH4	15	Detached House	Ground floor	Entrance (inside)	0.60 × 0.60, carpet	April 5
				Living room	2.00 × 2.00, carpet	
A3	4	Apartment	1 st floor	Entrance (inside)	1.00 × 0.50, carpet	April 5
				Living room	2.00 × 2.00, carpet	
A4	3	Apartment	2 nd floor	Entrance (inside)	2.00 × 2.00, ceramic tiles	April 3
				Living room	2.00 × 2.00, carpet	
DH5	40	Detached House	Ground floor	Entrance (inside)	2.00 × 2.00, carpet	April 3
				Living room	2.00 × 2.00, carpet	
H	10	House	Ground floor	Entrance	1.00 × 1.00, ceramic tiles	April 9
				Living room	2.00 × 2.00, ceramic tiles	

Note: In this study, an “apartment” is a dwelling in an apartment building that shares the main entrance of the building and some common areas around the building (such as parking and roof). A “house” is built on its own separate land. A “detached house” is an apartment in the ground floor of an apartment building but it has its own entrance and facilities; in that sense, it is like a house in living style but similar to apartments in structure.

Table S2: A summary about the rooms and floor surfaces from which the dust samples were collected at the Department of Physics, the University of Jordan. Samples were collected on April 29, 2015. The bare floor tiles used in the building was made cement filled with small marble stones.

			Surface area [m ²]	Surface type
P200	Office 200	1st floor	1.50 × 1.50	Carpet
P209	Office 209	1st floor	3.00 × 3.00	Bare floor
P300	Office 300	2nd floor	3.00 × 1.00	Carpet
P303	Office 303	2nd floor	1.50 × 1.50	Carpet
L230	Lecture room 230	1st floor	2.70 × 1.35	Bare floor
L102	Lecture room 102	Ground floor	3.90 × 1.50	Bare floor
WSa	Workshop, main area	Ground floor	1.50 × 1.50	Bare floor
WSb	Workshop, welding area	Ground floor	1.50 × 1.50	Bare floor
C1	1 st floor corridor	1st floor	1.80 × 3.00	Bare floor
BC	Big Corridor	Ground floor	2.70 × 2.70	Bare floor

Table S3: Polycyclic aromatic hydrocarbons (PAHs [ng/g]) concentrations in the dust samples collected from the dwellings (Maragkidou et al., 2016).

Location	Dwelling	PHE	ANT	FLA	PYR	BaA	CHR	BbF	BkF	BjF	BaP	IcdP	DahA	BghiP
Entrance	DH2	498	--	2037	354	44	191	324	90	90	23	46	--	55
	A2	169	--	147	157	65	104	116	67	51	64	60	--	111
	DH3	241	--	206	185	117	184	261	104	101	97	71	20	118
	DH4	1016	100	3879	997	114	530	308	113	94	45	52	--	60
	A3	4973	806	2039	946	--	51	26	24	11	10	--	361	19
	A4	197	--	110	89	--	44	40	22	15	12	15	--	26
	DH5	275	--	261	211	59	110	72	42	25	33	31	--	59
	H	91	--	53	47	--	14	12	8	5	--	--	--	11
Living Room	DH2	355	--	138	122	--	128	139	69	42	--	39	--	49
	A2	161	--	65	67	--	37	36	144	--	--	--	172	27
	DH3	512	98	562	448	175	236	242	89	72	74	53	--	76
	DH4	14413	2397	26630	15780	2184	2377	621	286	219	181	152	--	181
	A3	1273	259	2454	1685	402	468	197	97	68	86	81	150	88
	A4	239	--	91	84	--	32	28	23	10	8	--	107	20
	DH5	462	--	153	118	--	48	30	37	12	10	--	37	24
	H	197	--	111	102	--	42	32	24	13	9	--	149	23

Table S4: Polycyclic aromatic hydrocarbons (PAHs [ng/g]) concentrations in the dust samples collected from the educational building (Maragkidou et al., 2017).

Location		PHE	ANT	FLA	PYR	BaA	CHR	BbF	BkF	BjF	BaP	IcdP	DahA	BghiP
Office	P200	380	168	810	672	487	763	603	258	241	222	241	--	307
Office	P209	438	105	393	275	153	199	167	78	65	98	60	--	94
Office	P300	410	106	969	723	467	739	693	241	220	253	174	--	252
Office	P303	220	84	490	439	283	534	500	183	167	182	152	--	210
Lecture room	L102	186	77	186	182	107	168	159	73	61	69	61	33	83
Lecture room	L230	316	99	264	243	141	199	212	86	68	101	83	--	129
Workshop, main area	WSa	171	--	251	147	--	147	270	32	81	--	55	--	93
Workshop, welding area	WSb	190	--	106	205	--	43	38	14	14	22	19	--	63
1st floor Corridor	C1	710	168	632	517	374	496	415	184	164	255	147	89	213
Big Corridor	BC	471	74	519	489	224	334	262	110	96	137	77	--	123

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Table S5: Microbe concentration [cell equivalent/mg] based on the qPCR-DNA analysis of the dust samples collected from the dwellings.

Location	Dwelling	Gram-positive bacteria	Gram-negative bacteria	Penicillium Aspergillus spp.	Total fungal
Entrance	DH2	ND	1278700	600	14200
	A2	48200	1779800	7300	172300
	DH3	36700	246100	2600	10000
	DH4	29000	190500	1100	15300
	A3	348300	111300	1300	5700
	A4	17700	8900	200	500
	DH5	95800	478500	1900	16600
	H	ND	2254200	5500	35100
Living Room	DH2	NA	NA	NA	NA
	A2	49700	57200	1300	1400
	DH3	173500	254900	3900	30200
	DH4	11300	351200	1100	4400
	A3	959100	423000	2000	7700
	A4	77200	20700	600	600
	DH5	174500	82900	5400	3700
	H	265400	130900	26400	4200

5 **Table S6:** Microbe concentration [cell equivalent/mg] based on the qPCR-DNA analysis of the dust samples
6 collected from the educational building.

Location		Gram-positive bacteria	Gram-negative bacteria	Penicillium Aspergillus spp.	Total fungal
Office	P200	46600	376000	600	3800
Office	P209	109300	315900	500	2700
Office	P300	20200	302600	600	3300
Office	P303	21300	288000	1500	7900
Lecture room	L102	44500	225600	1400	5100
Lecture room	L230	24700	195300	1100	7200
Workshop, main area	WSa	8300	89700	700	2000
Workshop, welding area	WSb	5300	38700	5100	700
1st floor Corridor	C1	136000	124400	200	2700
Big Corridor	BC	107400	495000	2300	10700

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Table S7: Spearmans correlation (ρ) and p-value between the bacterial and fungal concentrations with the PAHs concentrations. The estimates in bold are considered statistically significant (or close to).

	Gram-positive bacteria		Gram-negative bacteria		Penicillium Aspergillus spp.		Total fungal	
	ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
Phenanthrene [PHE]	0.48	0.04	0.15	0.52	-0.37	0.10	0.10	0.67
Anthracene [ANT]	0.07	0.88	-0.08	0.84	-0.80	0.01	-0.68	0.05
Fluoranthene [FLA]	0.09	0.72	0.43	0.05	-0.41	0.07	0.26	0.26
Pyrene [PYR]	0.00	0.99	0.39	0.08	-0.31	0.17	0.21	0.36
Benz(a)anthracene [BaA]	-0.08	0.80	-0.30	0.32	-0.30	0.32	-0.58	0.04
Chrysene [CHR]	-0.08	0.76	0.36	0.11	-0.37	0.10	0.20	0.39
Benzo(b)fluoranthene [BbF]	-0.30	0.22	0.33	0.15	-0.44	0.05	0.13	0.57
Benzo(k)fluoranthene [BkF]	0.08	0.74	0.29	0.20	-0.34	0.13	0.14	0.54
Benzo(j)fluoranthene [BjF]	-0.23	0.35	0.27	0.24	-0.41	0.07	0.08	0.74
Benzo(a)pyrene [BaP]	-0.17	0.50	0.41	0.10	-0.33	0.18	0.15	0.56
Indeno(1,2,3,c,d)pyrene [IcdP]	0.12	0.68	0.20	0.45	-0.15	0.57	0.06	0.82
Dibenz(a,h)anthracene [DahA]	0.50	0.27	-0.68	0.11	-0.14	0.78	-0.71	0.09
Benzo(g,h,i)perylene [BghiP]	-0.28	0.25	0.28	0.21	-0.29	0.20	0.11	0.65

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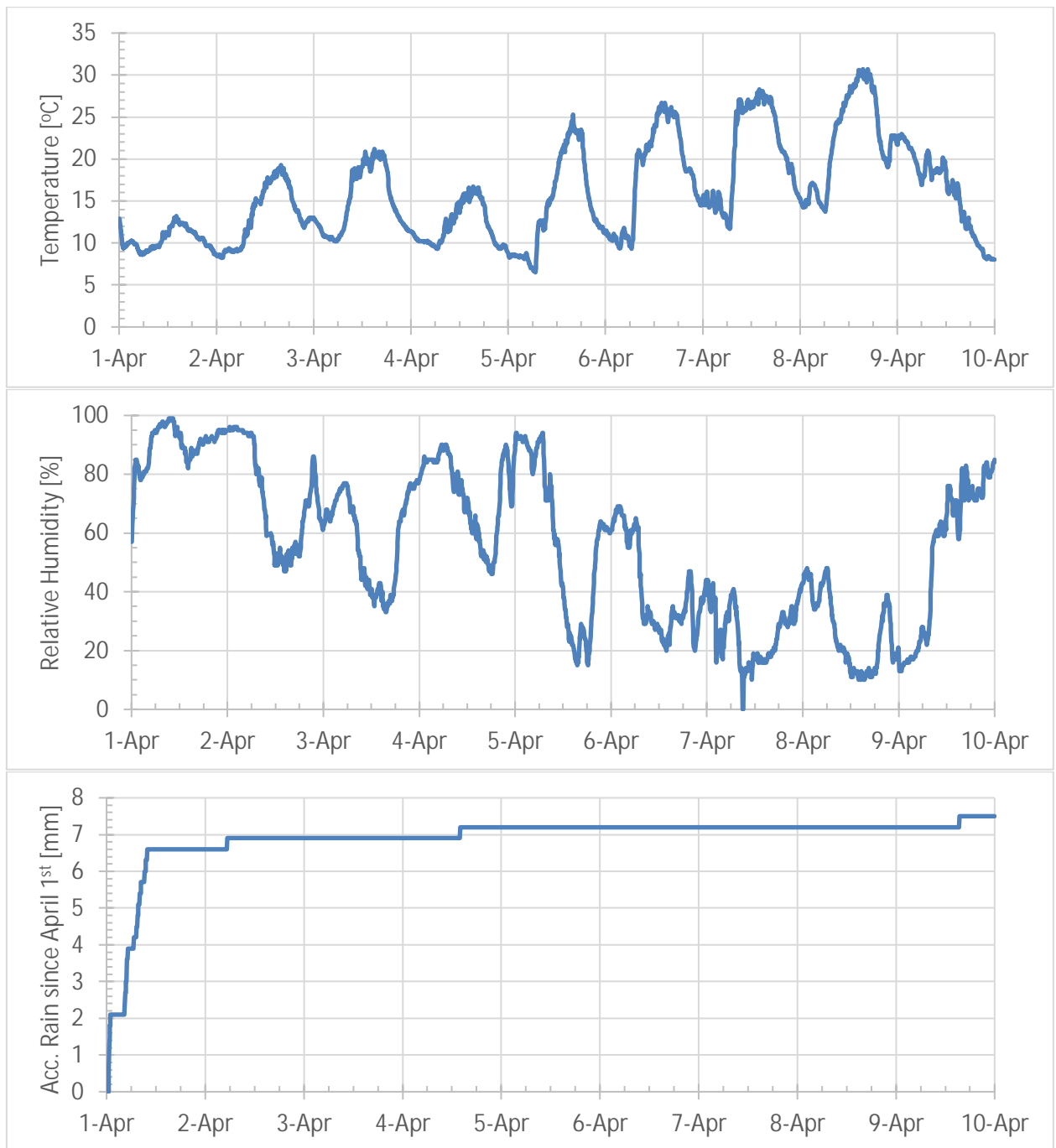


Figure S1: Ambient temperature, relative humidity, and accumulated rain (since April 1st).

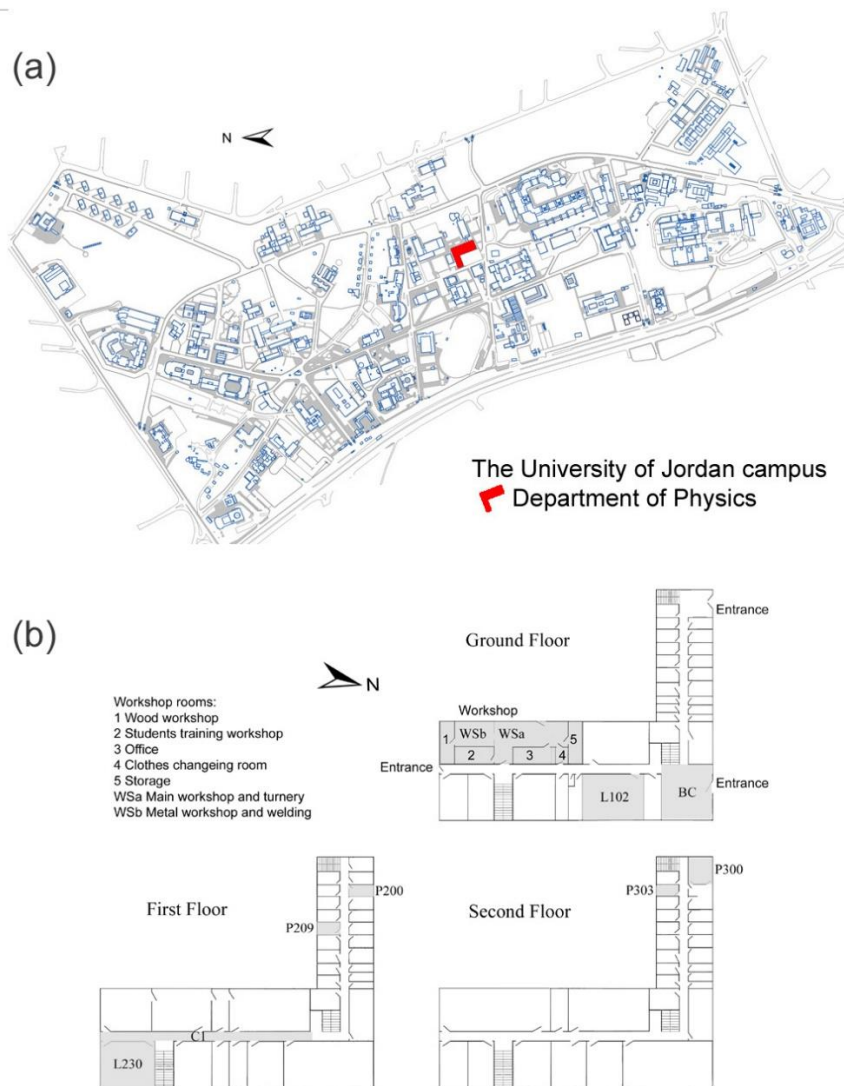


Figure S2: A map of the University of Jordan campus and a schematic chart of the Department of Physics with indications for the rooms from where floor dust samples were collected.